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AND POSITION BY PSD OPTICAL SENSOR

by

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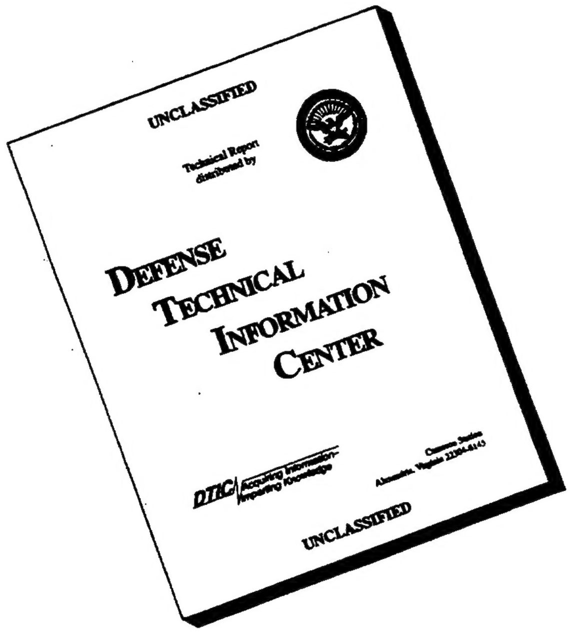

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Determination of a Target's Range and Position by PSD Optical Sensor[1]

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Abstract: A new method to measure the range and position of a space flight during the rendezvous and docking between two spacecraft are presented in this paper. A model is built to demonstrate the scheme experimentally. It is shown that the scheme is practicable.

Key Words: PSD (Position Sensitive Detector), rendezvous and docking, position measuring, range measuring

1. Introduction

One of the key techniques in spacecraft rendezvous and docking is real-time determination of the range and position of a target. At present, a CCD or CID device is most commonly used as the sensitive optical detector. However, both of them require a complicated focusing system and signal processing process [1]. The PSD (Position Sensitive Detector), a large-area photo diode with a uniform resistance layer, can offer from either of its electrodes an electric current containing information on the accurate position of the incident light spot. In addition, it enjoys a geometric resolution much higher than that of the CCD device and it requires only simple signal processing [2]. Therefore, the PSD sensitive detector is a prospective optical sensor for real-time determination of target range and position.

[1] This research project was sponsored by the National "863 Program.

2. Principle

The PSD sensitive detector consists of several subsystems including a modulating light source, optical head, signal processor, interface circuit and computer as shown in Fig. 1.

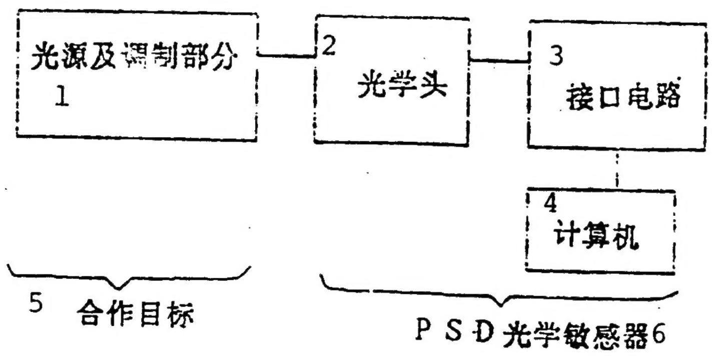

Fig. 1 Composition of PSD Sensitive Detector

Key: (1) Light source and modulation section;
(2) Optical head; (3) Interface circuit;
(4) Computer; (5) Cooperative target;
(6) PSD optical sensitive detector

The light source used in this system is a laser diode (LD), while the optical head includes an interference optical filter, imaging lens, PSD and electronic processing section as shown in Fig. 2.

Upon receiving optical information from a target, the PSD, through photoelectric transfer, can output current signals respectively from its four tube ends, two of which are output in the x direction while the other two are output in the in y direction. In this case, through I/U (current/voltage) conversion of these signals, and calculation of the quotient of the difference and sum of the correlated signals, the position of a light spot on the PSD photosensitive surface can be derived.

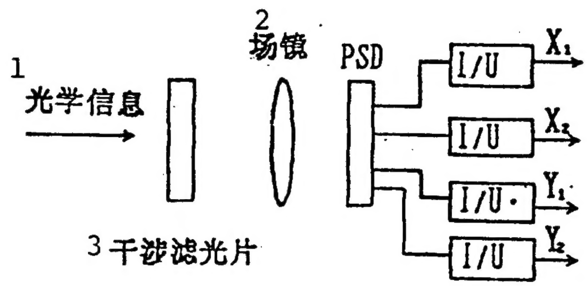

Fig. 2 Principle of Optical Head
Key: (1) Optical information;
(2) Field lens; (3) Interference
optical filter

Here, a three light spot method is proposed, which is designed to calculate the target range and position relative to the PSD. Fig. 3 shows a front view of a cooperative target specially designed in conformity to this method where the target is replaced by three light sources with modulating circuits. Fig. 4 shows the auxiliary measuring coordinate system defined in the three light spot method. Fig. 5 shows a projection drawing of the cooperative target on an image plane, where a′ and b′, respectively, are projections of a and b; h is the vertical distance from C′ to A′ and B′.

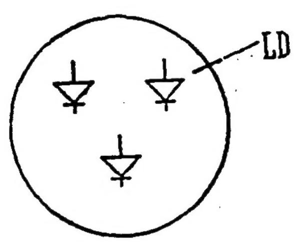

Fig. 3 A Front View of the Cooperative Target

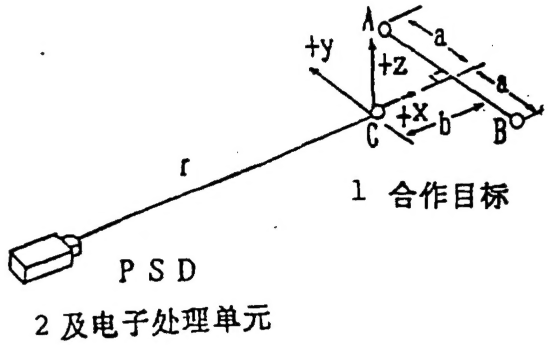

Fig. 4 Coordinate Measuring System Defined

Key: (1) Cooperative target; (2) PSD and electronic processing unit

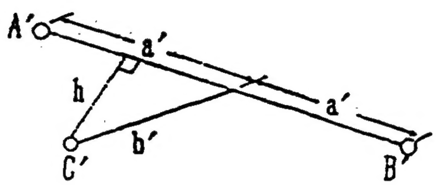

Fig. 5 A Projection Drawing of the Cooperative Target on the Image Plane

Suppose there is a unit vector pointing from the target center to the PSD, and the coordinates of the vector end are (-x, -y and -z), where "-" indicates that all the values are positive, then:

$$x^2+y^2+z^2=1 \tag{1}$$

Based on the similar triangle in the orthogonal projection drawing shown in Fig. 6, and Pythagorean theory, the following equation can be derived:

$$a' = a\sqrt{x^2+z^2} \tag{2}$$

$$b' = b\sqrt{y^2 + z^2} \tag{3}$$

$$h = bz/\sqrt{x^2 + z^2} \tag{4}$$

By defining

$$D = \frac{(a'b)^2}{(ab')^2} \tag{5}$$

and

$$k = \frac{b'(1 + D)}{2hD^{1/2}} \tag{6}$$

and substituting equations (2), (3) and (4) in Eqs. (5) and (6), then

$$D = \frac{x^2 + z^2}{y^2 + z^2} \tag{7}$$

and

$$k = \frac{1 + z^2}{2z} \tag{8}$$

can be derived.

From here,

$$z = k - \sqrt{k^2 - 1} \tag{9}$$

$$x = \left(\frac{D - z^2}{1 + D}\right)^{1/2} \tag{10}$$

$$y = \left(\frac{1 - Dz^2}{1 + D}\right)^{1/2} \tag{11}$$

are obtained.

Since the image in Fig. 6 appears r/f times larger than the image observed by the PSD, i.e.

$$\frac{r}{f} = \frac{a\sqrt{x^2 + z^2}}{a'} \tag{12}$$

the distance between the actual measurement target and the PSD is

$$r = \frac{a\sqrt{x^2 - z^2}\ f}{a'} \tag{13}$$

where f is the lens focal length. Thus, the position of the PSD in the coordinate system with the cooperative target center as the origin of the coordinate point is:

$$\begin{bmatrix} x \cdot r \\ y \cdot r \\ z \cdot r \end{bmatrix} \tag{14}$$

It is known from the foregoing derivation that a, b and f are given quantities; a′, b′ and h can be derived through a simple geometric relationship, and the target range and position relative to PSD can be directly calculated through computer processing of the signals after I/U conversion and then A/D conversion.

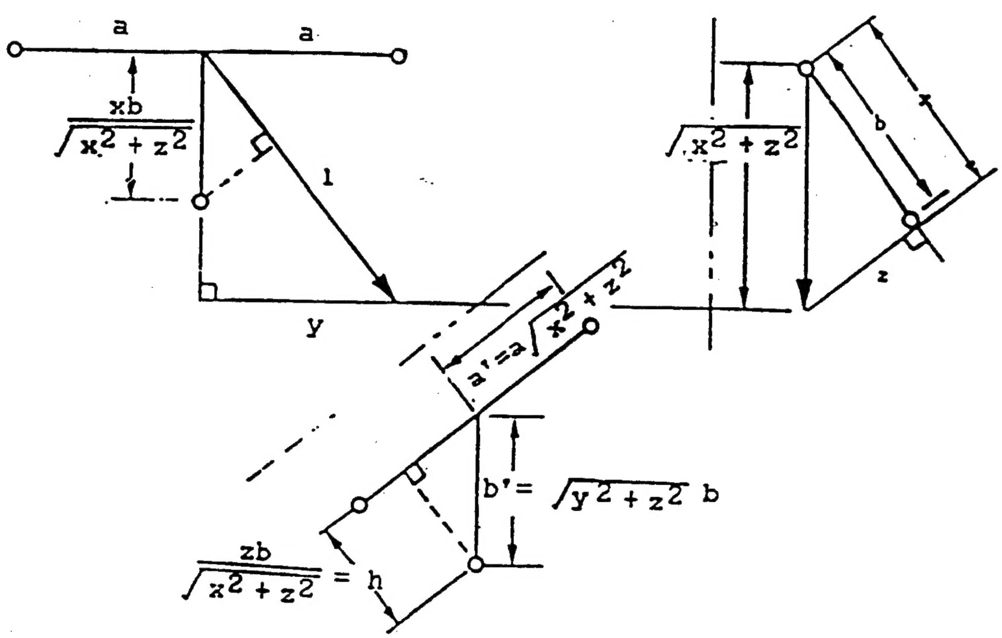

Fig. 6. Front Projection for Determining a',b',h

3. Experimental Study

The PSD used in the experiment was constructed by the Shanghai Energy Research Institute. With a 925nm wavelength spectral response peak value, it has a ±250μm detection error (within 75%) and 10μm position resolution.

The experiment was carried out as follows:

(1) The PSD position relative to the cooperative target was measured through fixing the target and moving the PSD in the horizontal direction. The linear output characteristics of the PSD in the horizontal direction were observed. Table 1 shows a set of experimental data, while Fig. 7 displays a curve drawn on the basis of these data.

Table 1 Unit: Millimeter (mm)

a=10.3	b=17.8	f=310.5	r=2055.0
r_m (x, y, z)	1987.75 (-1976.9, -5[illegible], 22[illegible])	2031.72 (-2021.3, -308.3, 205.5)	2044.61 (-2035.4, -205.5, 195.2)
	2052.12 (-2044.6, -102.8, 178.8)	2052.41 (-2043.5, 102.8, 191.1)	2044.77 (-2030.1, 205.5, 242.5)
	2048.07 (-2021.5, 287.7, 232.2)	2017.51 (-2005.3, 390.5, 221.94)	

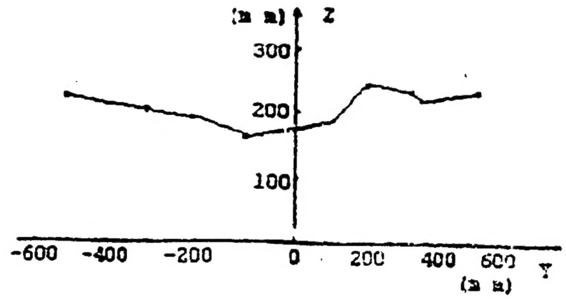

Fig. 7. Measurements of the Target Moving in the Horizontal Direction

(2) The PSD position relative to the cooperative target was measured by fixing the target and moving the PSD in the vertical direction. The linear output characteristics of the PSD in the vertical direction were observed. Table 2 shows a set of experimental data, while Fig. 8 displays a curve plotted in accordance with these data.

Table 2 Unit: Millimeter (mm)

a=10.3	b=17.8	f=310.5	r=2055.0
r_m (x, y, z)	2046.48 (-2031.8, 185.0, -246.6)	2046.00 (-2039.5, 191.1, -164.4)	2045.34 (-2044.9, 199.3, -41.10)
	2046.83 (-2044.3, 182.5, [illegible])	2046.93 (-2035.[illegible], 180.8, 185.0)	2045.80 (-2028.2, 195.2, 26[illegible])
	2048.07 (-2021.[illegible], 168.5, 328.8)	2047.37 (-2009.6, 178.3, 390.5)	2049.39 (-1997.0, 164.4, 452.[illegible])

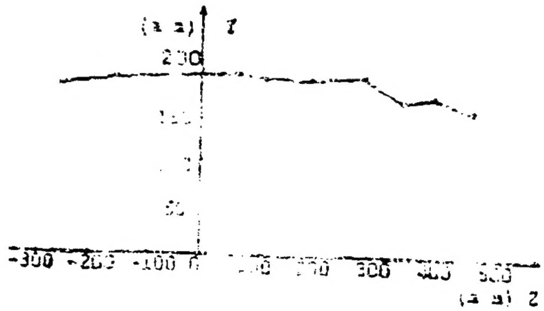

Fig. 8. Measurements of the Target Moving in the Vertical Direction

It can be seen from the two curves that the PSD has ideal output linearity and at the same time, the orbital path of the target was also measured as vertical or horizontal when the target was moving in the vertical or horizontal directions.

(3) The relative range of the cooperative target was measured by moving the target back and forth. Table 3 shows a set of experimental data, while Fig. 9 displays the difference between the actual range r based on these data and measured range r_h as well as the experimental curve of r, with a maximum error 0.13m of this experimental range measurement.

Table 3 Unit: Millimeter (mm)

r	2255.0	2055.0	1855.0	1600.0	1500.0	1400.0
r_h	2120.88	1987.75	1805.15	1522.28	1466.20	1384.32
$r - r_h$	134.12	67.25	49.85	77.72	33.8	15.68

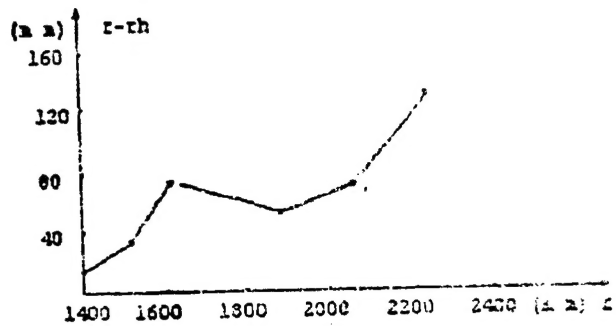

Fig. 9 Relationship between Measurement Error $r-r_h$ and r

4. Conclusions

Measuring the relative range and position of a target with the PSD sensitive detector and three light spot method is a new endeavor. The experiment demonstrated that this device features excellent output linearity, rapid measurement speed, high real-time performance and 0.13m maximum error of range measurement. Once improved, this equipment will be able to accurately measure the relative range and position of the target, and satisfy the requirements for spacecraft rendezvous and docking. Further research on its practicability is expected so as to meet the need for medium and short-range measurements and visual robotic system in future spacecraft rendezvous and docking.

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